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(54) **HYBRID HIGH VOLTAGE DC CONTACTOR WITH ARC ENERGY DIVERSION**

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(51) **Int. Cl.**
H01H 9/30 (2006.01)
H01H 9/38 (2006.01)

(52) **U.S. Cl.** **361/13**; 361/2; 361/8

(58) **Field of Classification Search** 361/13, 361/2, 8
See application file for complete search history.

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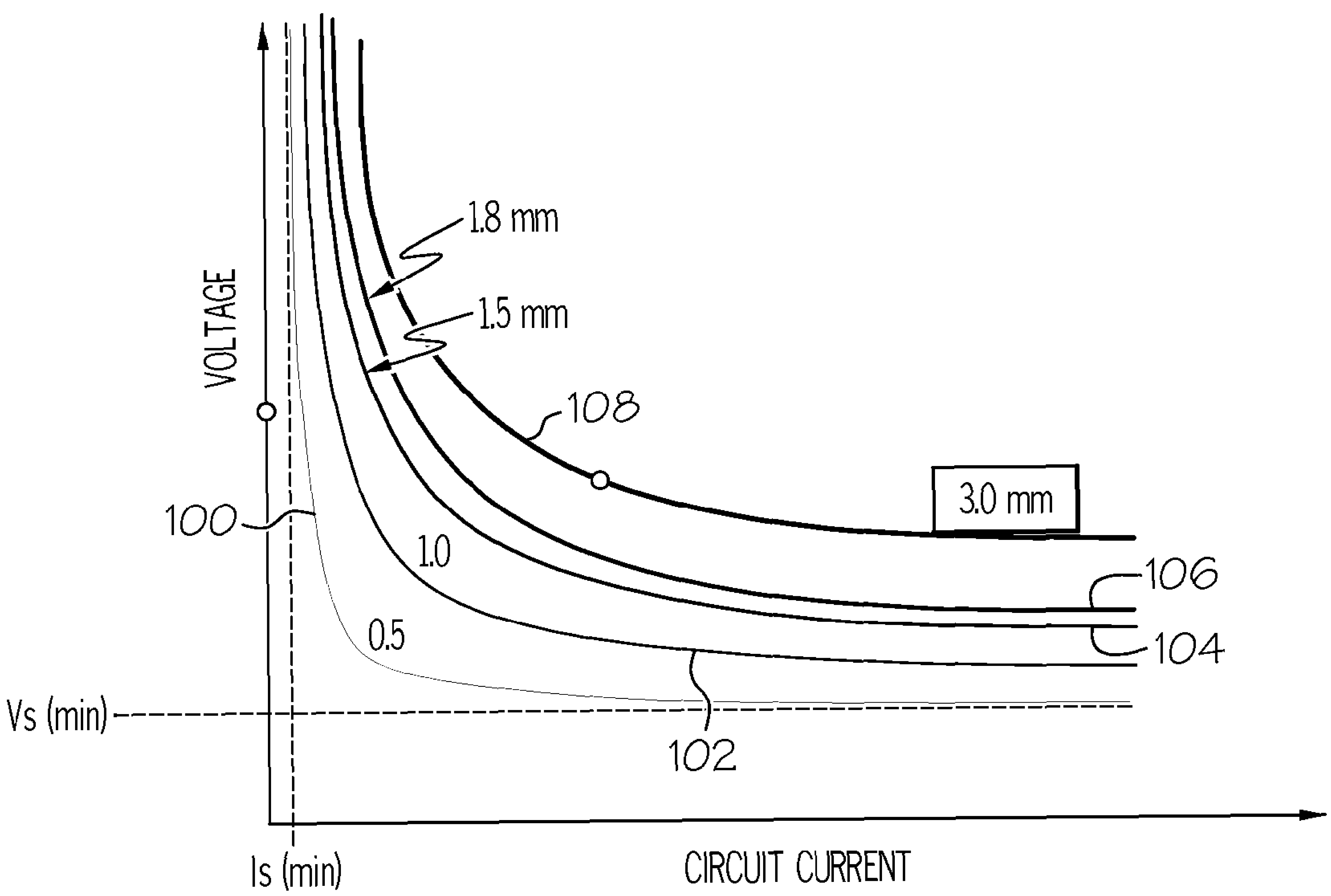
(57) **ABSTRACT**

A contactor may operate to interrupt current in a circuit while the circuit is operating under load. A shunt is provided to by-pass surge power current around contacts to reduce arcing. The shunt includes a solid-state switch that may be operated in a series of pulses during movement of the contacts. The pulse control unit may detect a potential for arcing and then provide for periodic pulsing operation of the shunt. Because the solid-state switch may operate discontinuously, the contactor may be constructed with a switch that is selected on a basis of its pulse rating.

13 Claims, 4 Drawing Sheets



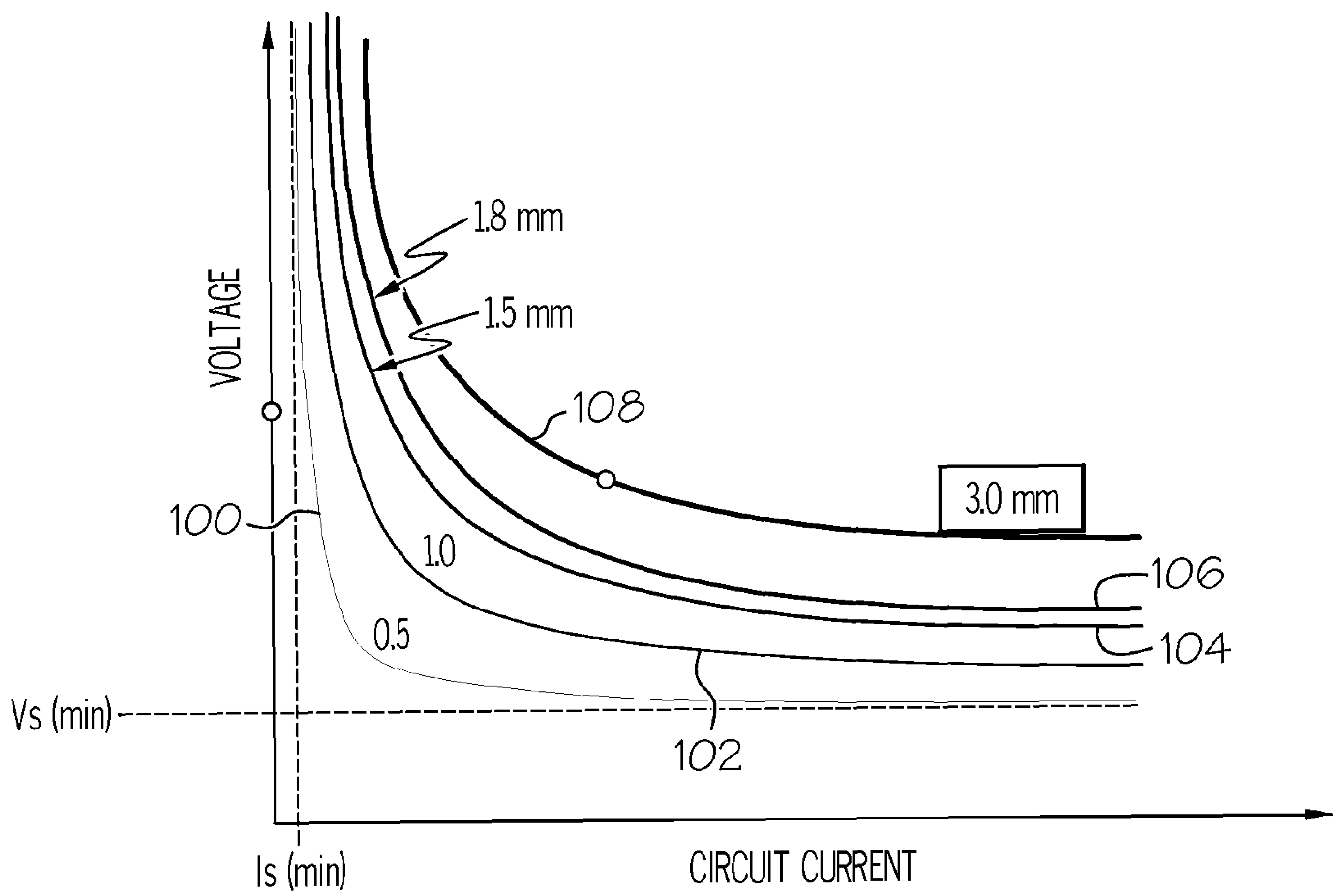

1.8 mm
1.5 mm
VOLTAGE
108
3.0 mm
100
1.0
106
0.5
104
Vs (min)
102
Is (min)
CIRCUIT CURRENT

FIG. 1

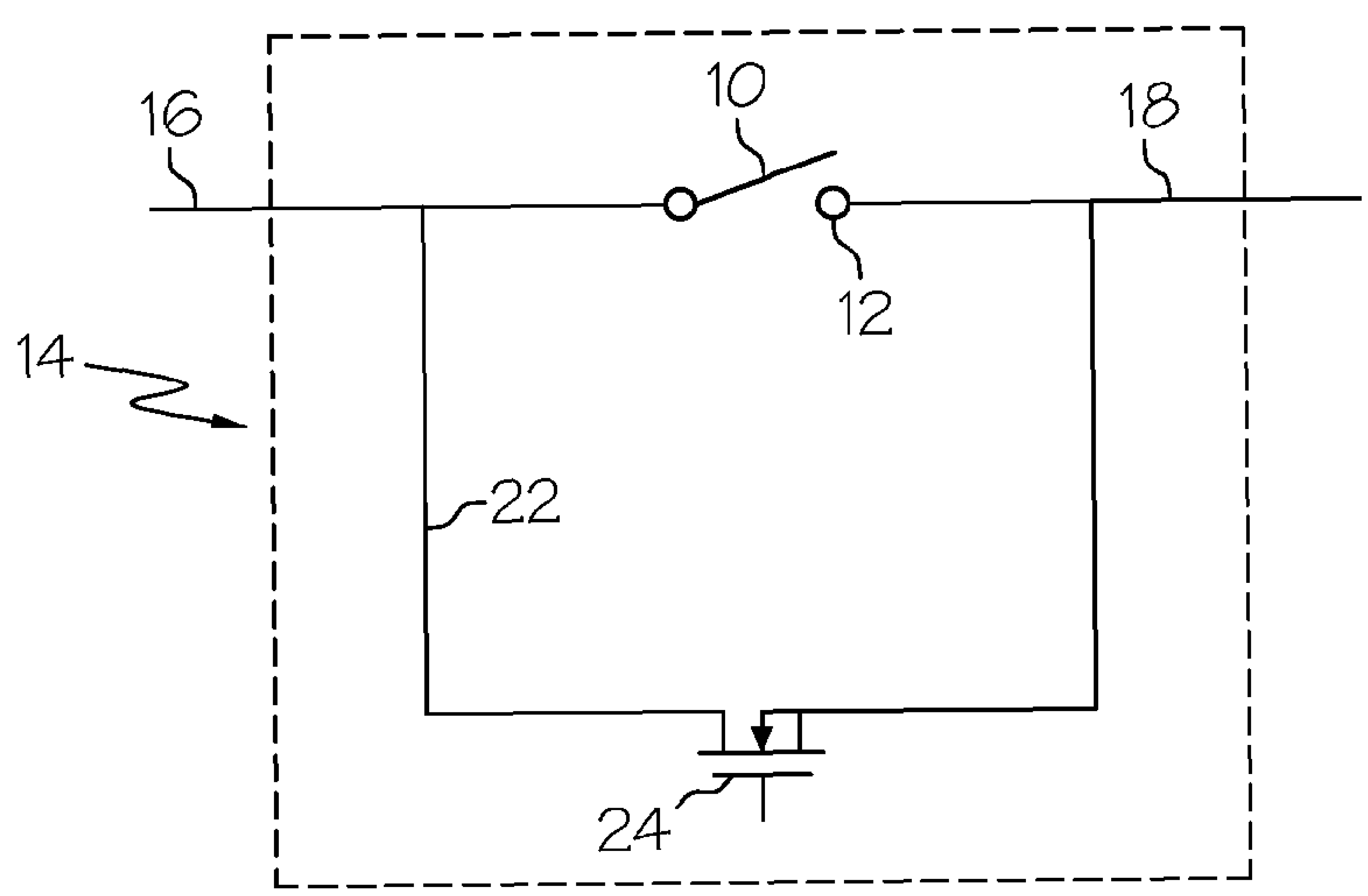

16
10
18
12
14
22
24

FIG. 2

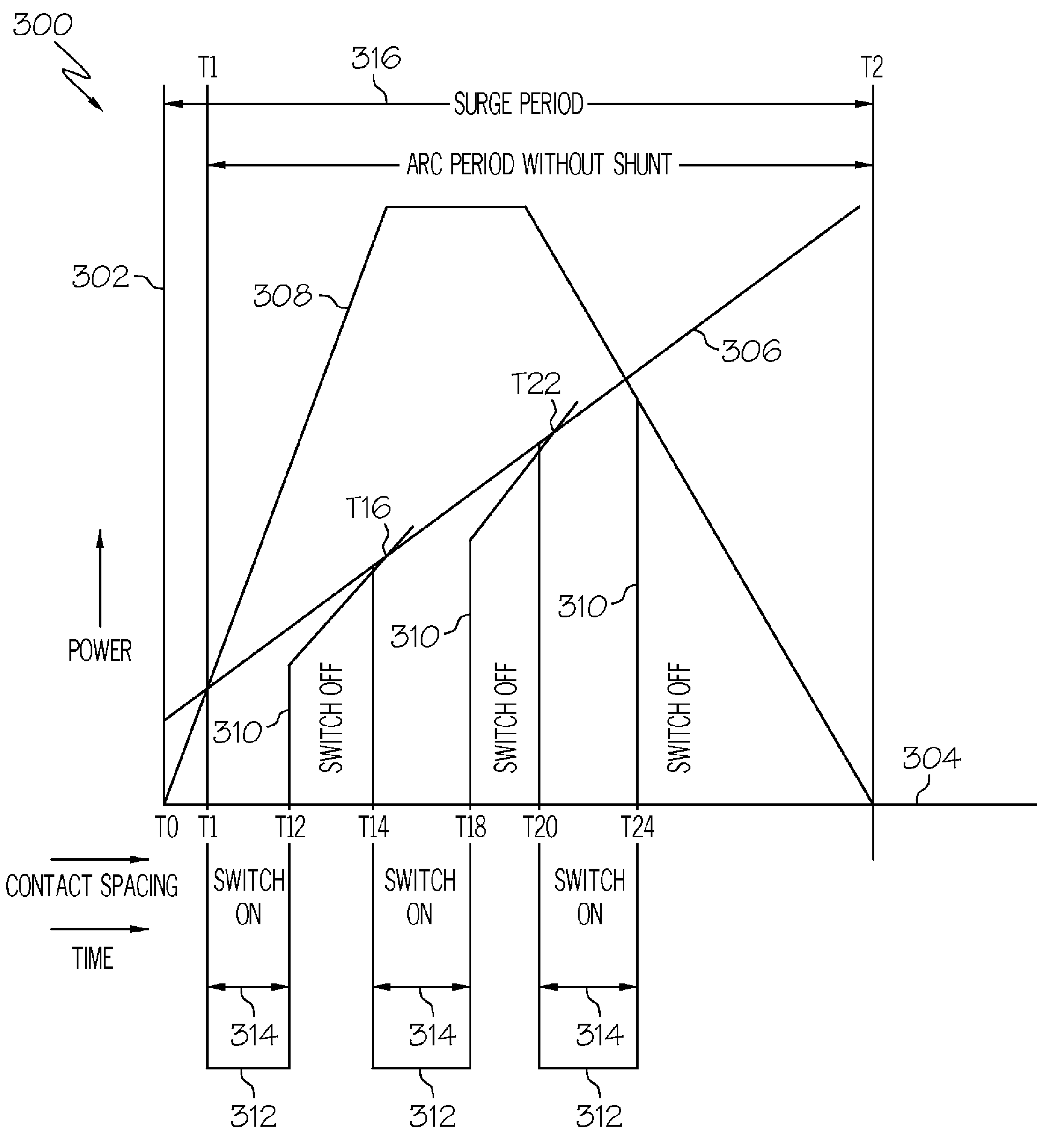

300
T1
316
T2
SURGE PERIOD
ARC PERIOD WITHOUT SHUNT
302
308
306
T22
T16
POWER
310
310
310
310
SWITCH OFF
SWITCH OFF
SWITCH OFF
304
T0
T1
T12
T14
T18
T20
T24
CONTACT SPACING
TIME
SWITCH ON
SWITCH ON
SWITCH ON
314
314
314
312
312
312

FIG. 3

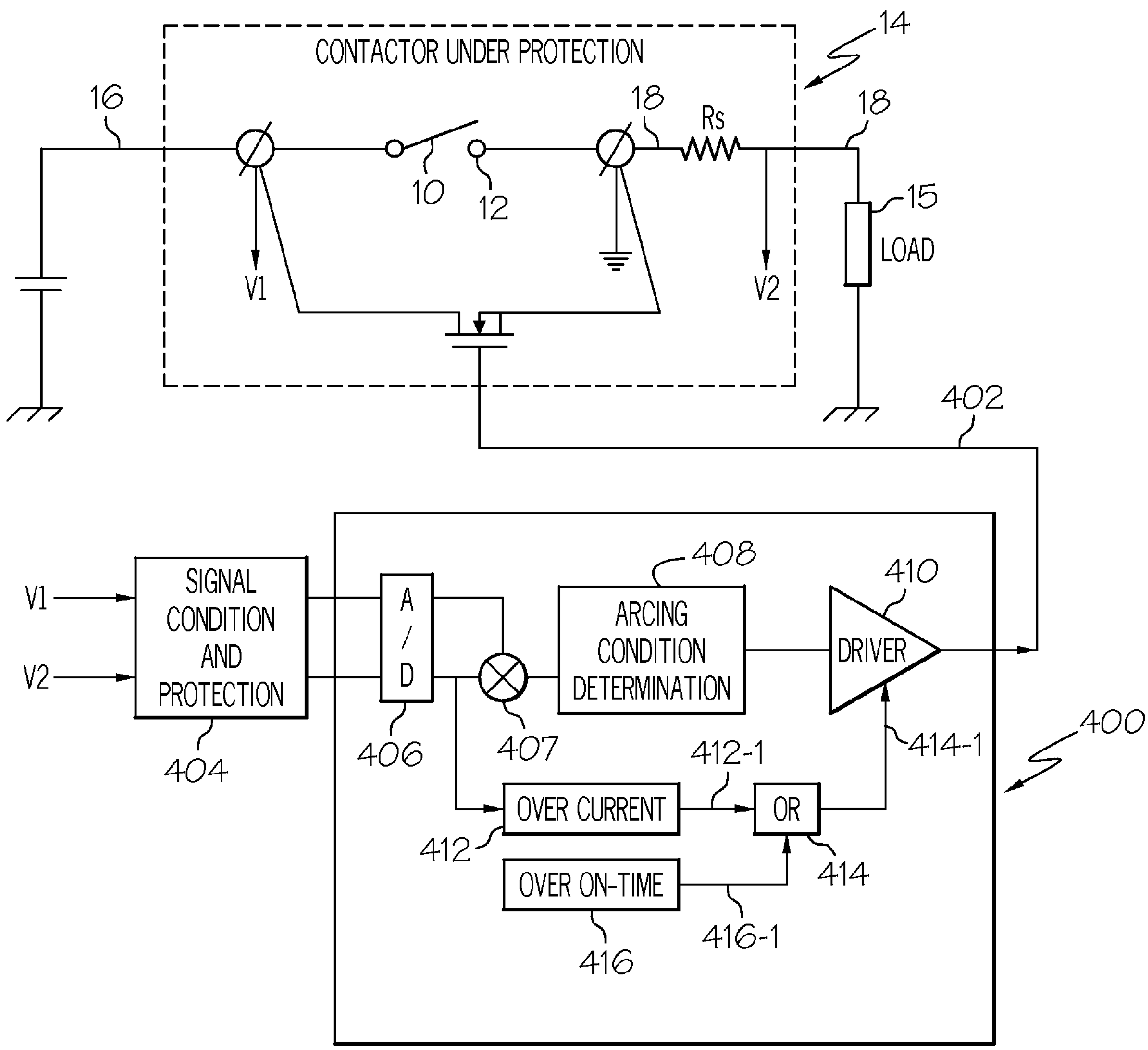

CONTACTOR UNDER PROTECTION
14
16
18
Rs
18
10
12
15
LOAD
V1
V2
402
SIGNAL CONDITION AND PROTECTION
V1
V2
404
A / D
406
407
ARCING CONDITION DETERMINATION
408
DRIVER
410
414-1
400
OVER CURRENT
412
412-1
OR
414
OVER ON-TIME
416
416-1

FIG. 4

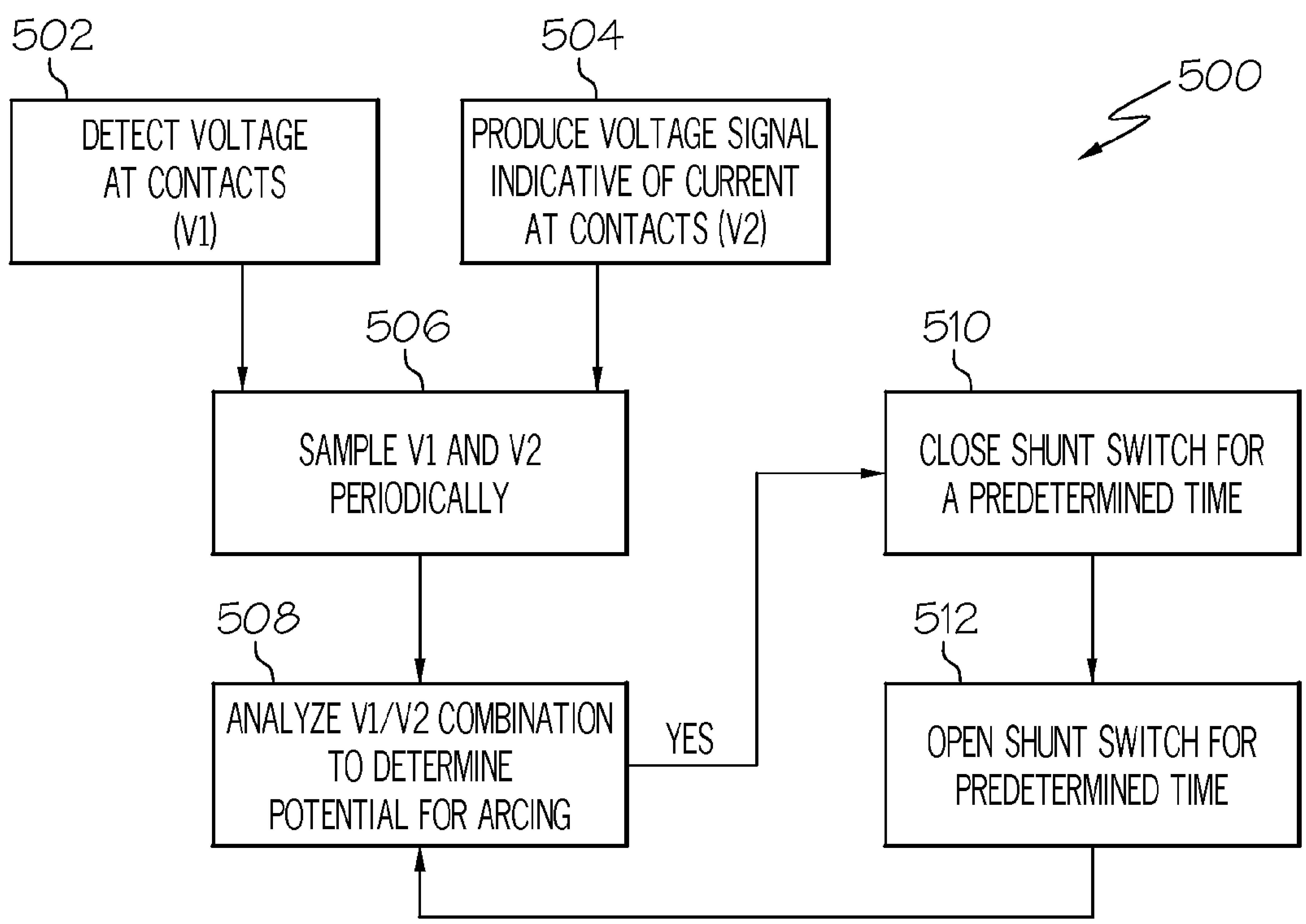

502
504
500
DETECT VOLTAGE AT CONTACTS (V1)
PRODUCE VOLTAGE SIGNAL INDICATIVE OF CURRENT AT CONTACTS (V2)
506
510
SAMPLE V1 AND V2 PERIODICALLY
CLOSE SHUNT SWITCH FOR A PREDETERMINED TIME
508
512
ANALYZE V1/V2 COMBINATION TO DETERMINE POTENTIAL FOR ARCING
YES
OPEN SHUNT SWITCH FOR PREDETERMINED TIME

FIG. 5

HYBRID HIGH VOLTAGE DC CONTACTOR WITH ARC ENERGY DIVERSION

BACKGROUND OF THE INVENTION

The present invention is in the field of electrical switches, and more particularly, contactors for high-power direct current (DC) circuits.

In certain circumstances there is a need to interrupt current in a DC circuit while the circuit is carrying a high current (e.g. 50 to 200 amps). These circumstances may arise, for example, when an electrical load on the circuit becomes excessive or when a short-circuit fault develops. In order to accommodate such eventualities, high-current DC circuits may incorporate heavy-duty contactors.

Rapid interruption of current may produce an induced surge of energy. This energy may produce arcing in a contactor. Some heavy-duty contactors may be constructed so that this arcing may be tolerated. Other prior-art contactors may be constructed so that such arcing is reduced.

In some prior-art contactors, a gas-tight or liquid-tight enclosure may be provided for the contactor or its contact elements. A gas or liquid may surround the contact elements and prevent oxidation of the elements when arcing occurs. In other prior-art contactors, selected arc-tolerant metallic alloys may be used for contact elements.

Some prior-art contactors may be provided with an electrical shunt that may by-pass an energy surge around the contact elements. Such a shunt may comprise a high-power field-effect transistor (FET) or similar device. The FET must be able to tolerate a high-current surge without damage. For example, a shunt or by-pass rated at about 1500 amps may be needed for a contactor rated at 150 amps that may be required to open with a “short circuit” condition.

Prior-art high-power contactors with protected contact elements or with by-pass shunts are expensive, heavy and complex. These characteristics of prior-art contactors are of particular concern to aircraft designers. Aircraft designs are evolving in a direction that is often referred to as “more electric architecture” (MEA) design. In new MEA designs various operational functions which were formerly performed with hydraulic and pneumatic systems are now performed electrically. These electrical operations are often performed with high amperage DC motors and controls. In this context, MEA designs may incorporate an increasing number of contactors which may interrupt high-amperage DC. MEA designs could be improved if high-power contactors could be made lighter, less expensive and more reliable than prior-art contactors.

As can be seen, there is a need to provide improved contactors which are capable of interrupting high amperage DC. Additionally, there is a need to provide such contactor with low weight so that they may be effectively employed in aircraft.

SUMMARY OF THE INVENTION

In one aspect of the present invention, an apparatus for interrupting current in a circuit comprises contacts through which the current passes. The contacts move away from one another during current interruption. A shunt is provided to by-pass surge power around the contacts when current is interrupted. The shunt is operative during a portion of time period that the contacts move and the shunt is inoperative during a portion of said time period.

In another aspect of the present invention, an electrical power circuit comprises a contactor with movable contacts, an electrical shunt to by-pass current around the contacts, and a pulse control unit to periodically operate the shunt during movement of the contacts.

In still another aspect of the present invention, a method for interrupting current in a circuit under load conditions comprises the steps of moving conducting contacts away from one another for a predetermined time period, detecting electrical power at the contacts during the step of moving the contacts, determining if the detected power is sufficient to initiate arcing at the contacts, operating an electrical shunt around the contacts for a portion of the predetermined time period if the detected power is sufficient for arcing initiation, and disabling the electrical shunt for a portion of the time period.

These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is graphical representation of an arc initiation relationship in accordance with the invention;

FIG. **2** is a schematic diagram of a contactor in accordance with the invention;

FIG. **3** is a symbolic graphical representation of operational aspects of a contactor in accordance with the invention;

FIG. **4** is a block diagram of a current interruption system in accordance with the invention; and

FIG. **5** is a flow chart of a method of performing current interruption in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best defined by the appended claims.

Broadly, the present invention may be useful for interrupting high-amperage current in a circuit. More particularly, the present invention may provide light-weight shunted contactors to perform such interruption. The present invention may be particularly useful in vehicles such as aircraft.

In contrast to prior-art contactors, among other things, the present invention may provide a pulse-rated shunt for a contactor. The present invention, instead of employing a prior-art steady-state rated shunt for a contactor, may, utilize a lower-rated shunt. The lower-rated shunts may be operated in a series of conducting pulses to reduce or preclude arcing in a contactor. By avoiding continuous conduction of current through the shunt, a smaller, lower-rated shunt (e.g. an FET) may be used to protect a contactor from arcing damage.

Referring now to FIGS. **1** and **2**, a series of graph lines show various combinations of surge voltage Vs and surge current Is that may initiate arcing between contacts **10** and **12** of a contactor **14** during interruption of current being provided to an electrical load. High surge voltages and currents may arise in conductors **16** and **18** during such an interruption. A graph line **100** may represent an arc-initiation relationship between surge voltage Vs and surge current Is when the contacts **10** and **12** are separated by a first distance (e.g. 0.5 millimeters [mm]). A graph line **102** may represent an arc-initiation relationship between Vs and Is when the contacts **10** and **12** are separated by a second distance (e.g. 1.0 mm). In other words, to use graph line **100** as an example, at a contact spacing of 0.5 mm, an arc may not develop if the surge voltage is less than a Vs (min) or if the surge current is less than Is (min). Furthermore an arc may not develop at any combination of Vs and Is that is below the graph line **100**. The graph line **100** may be considered to represent a surge-power limit curve, i.e., a plot of a Vs*Is. It may represent the concept that if surge power remains below the graph line **100**, then an arc may not initiate at 0.5 mm spacing between the contacts **10** and **12**.

It may be seen that as spacing between the contacts **10** and **12** increases, a combination of Vs and Is must become larger in order for an arc to initiate. Graph lines **102**, **104**, **106** and **108** may illustrate this concept. Graph line **102** represents a surge-power limit curve for contact spacing of 1.0 mm. Graph lines **104**, **106** and **108** may represent surge-power limit curves for contact spacings of 1.5 mm, 1.8 mm and 3.0 mm respectively.

Referring now to FIG. **3**, a graph **300** may symbolically illustrate how arc initiation may be delayed or entirely precluded in accordance with the invention. The graph **300** may represent surge power on a vertical axis **302**. Spacing between the contacts **10** and **12** of FIG. **2** may be represented on a horizontal axis **304**. When the contactor **14** of FIG. **2** interrupts current, the contacts **10** and **12** may move away from one another during a brief but finite time period (e.g., about 1 to 2 milliseconds [msec]). Thus, the axis **304** may also represent time.

A sloped line **306** may represent a compilation of the surge-power curves of FIG. **1** plotted against time. In other words, the line **306** may represent a surge power boundary below which arcing may not initiate between the contacts **10** and **12**. As the contacts **10** and **12** move further and further apart, increasing amounts of power may pass between the contacts **10** and **12** without initiation of arcing.

Referring now to FIGS. **2** and **3** a novel application of a shunt in accordance with the present invention may be understood. The contactor **14** may be provided with a shunt **22** interconnected so that current may by-pass the contacts **10** and **12**. The shunt **22** may comprise a solid-state switch **24** such as a field effect transistor (FET) or any of a number of conventional solid-state switching devices. The shunt **22** may operate responsively to surge power that may develop during current interruption. When surge power exceeds a predetermined limit, the switch **24** may close and allow current to by-pass the contacts **10** and **12**. An apparatus and method for producing selective operation of the shunt **22** is described hereinbelow with reference to FIGS. **4** and **5**.

In FIG. **3**, a graph line **308** may represent surge power as a function of time. It may illustrate dynamic conditions that could arise when the contacts **10** and **12** are moved away from one another while current is being supplied to the load **15**. Surge power may begin developing and increasing as soon as the contacts **10** and **12** no longer touch one another (time T**0**). At a time T**1** the surge power may have increased to a level at which the surge power may exceed the surge power boundary **306**. Under this condition an arc could initiate between the contacts **10** and **12**. But, if the switch **24** is closed at or before time T**1**, then surge power may be shunted away from the contacts **10** and **12** and the surge power at the contacts may be diminished. In the event of such shunting, the surge power at the contacts **10** and **12** may be represented by a graph line **310**.

If shunting were not to occur at or before time T**1**, surge power at the contacts **10** and **12** could continue to increase in accordance with the graph line **308**. In such a case, arcing could initiate and continue until surge power is dissipated, i.e., until a time T**2** on the graph **300**.

If shunting occurs at or before time T**1**, overall surge power may continue to increase as a function of time but there may be a reduced amount of the surge power at the contacts **10** and **12**. The graph line **310** may represent a portion of the surge power at the contacts **10** and **12**, i.e., a "contact portion". A graph line **312** may represent a "shunt portion" of surge power as a function of time.

The shunt portion line **312** may have a pulsed configuration. This configuration may be associated with a novel operation of the shunt switch **24** in accordance with the invention. The switch **24** may be closed at or before the time T**1**. At that time the surge power may pass through the switch **24**. At a later time, T**12**, the switch **24** may open and surge power may once again be applied to the contacts **10** and **12**. An exemplary time period between T**1** and T**12** may be about 5 to 10 microseconds (μsec). The contact portion of surge power at time T**12** may be greater than the contact portion at time T**1**, but the contacts **10** and **12** may be further apart at the later time T**12**. If the contact portion of surge power remains below the surge power boundary (line **306**) after time T**12**, then arcing may not initiate.

Surge power may continue rising after time T**12**. If such rising were left to proceed, the contact portion of surge power may exceed the surge power boundary **306** at a later time T**16**. But, at or before the time T**16** (e.g., at a time T**14**), the switch **24** may again close. Surge power may once again by-pass the contacts **10** and **12**. Consequently the surge power boundary **106** may not be crossed by the contact portion of surge power and arcing may not initiate.

A similar sequence of events may occur at a time T**18** when the switch **24** may again open. At the time T**18**, contact surge power may begin to rise at a rate that may result in the contact portion of surge power crossing the surge power boundary at a later time T**22**. Such a crossing may be precluded if the switch **24** were to close at or before the time T**22** (e.g., at a time T**20**).

The time period between T**1** and T**12** may be considered a pulse period **314** for the switch **24**. Similarly a time period between T**14** and T**16** may be considered a pulse period **314** for the switch **24**. A series of similar pulse periods **314** may develop during a surge period **316**, i.e., a period of time between T**0** and T**2** required for dissipation of the surge power. For purposes of simplicity, only a few of the switch pulse periods **314** are shown symbolically in FIG. **4**. It may be noted that if the surge period **316** extends for an exemplary 1 msec to 2 msec., then up to about twenty of the 5 μsec to 10 μsec switch pulses **314** may be produced in that time period.

In a pulsed mode of operation, the switch **24** may conduct current during a fractional part of the surge period **316**. Pulsed operation of the switch **24** may allow for use of a solid-state switch (e.g. a FET) with a lower current rating lower than a FET that may be required to continuously conduct current throughout the surge period **316**. For example, in the prior-art, a FET with a nominal rating of 1500 amps may be required to continuously shunt all of the surge power for an exemplary 150 amp circuit. But, in the case of the present invention, an exemplary FET may be used with a "pulse-rating" of 1500 amps. Pulse rating for an FET may be about 2.5 times as great as its nominal rating. Thus, a FET with a nominal rating of 600 amps (1500 amps/2.5) may be used to provide arc suppression for a contactor in the exemplary 150 amp circuit. In other words, the switch **24** of the present invention may have a nominal rating that is at least 50% lower than a nominal rating of a prior-art shunt switch.

An FET with a nominal rating of 600 amps may be smaller, lighter and less expensive than a FET with a nominal rating of 1500 amps. It may be seen therefore that when contactors are constructed and operated in accordance with the present invention, the contactors may be smaller, lighter and less costly than their prior-art counterparts.

Referring now to FIG. **4** a block diagram may illustrate how the contactor **14** may be constructed and operated in accordance with the invention. A pulse control unit **400** may provide switching signals **402** to the solid-state switch **24**.

The pulse control unit **400** may produce the switching signals **402** responsively to voltage and current information from the contactor **14**. In particular a voltage signal V**1**, indicative of voltage in the conductor **16** may be provided to the pulse control unit **400**. A second voltage signal V**2** indicative of current in the conductor **18** may also be provided to the pulsing circuit **400**.

The V1 and V2 signals may be provided to the pulse control unit **400** through a conventional signal conditioning and protection block **404**. The pulse control unit **400** may comprise an analog to digital (A/D) converter **406**, a multiplier **407** and an arcing-condition determination block **408**. The block **408** may analyze a digital representation of the V1 and V2 signals against a clock signal (not shown) to determine if their combined power may initiate arcing between the contacts **10** and **12**. The block **408** may perform its analysis repetitively at an exemplary sampling rate of about 0.1 μsec. In the event that arcing potential is determined by the block **408**, a driver **410** may be activated to close the solid-state switch **24**. This may shunt surge power through the switch **24**. If current through the switch **24** increases beyond a predetermined level, an over-current block **412** may produce a signal **412-1** to an OR gate **414**. An over-on-time block **416** may determine a length of time that the switch **24** is closed or "on". This on-time may be compared against a predetermined time (e.g., a switch pulse period of 5 to 10 μsec.). An over-on-time signal **416-1** may be provided to the OR gate **414** after the predetermined amount of on-time for the switch **24**. If either of the signals **412-1** or **416-1** are received by the OR gate **414**, a switch-opening signal **414-1** may be provided to the driver **410** and the switch **24** may be directed to open. A shunt of current of a desired magnitude and time duration may thus be produced based on the predetermined level of current that may be established in the block **412** and the predetermined time that may be established in the block **416**.

Effectiveness of the present invention may be dependent on a proper selection of shunt pulse time. In an exemplary case of a surge period of about 1 msec. it has been found that a shunt pulse period of about 5 μsec may be effective in reducing or even eliminating arcing. One of the contactors **14** may experience some brief arcing (less than 5 μsec in duration) or none at all when the shunt **18** is operated with 5 μsec pulses.

However, it has also been found that a shunt pulse period of about 1 μsec may not effective in reducing or precluding arcing. When, in the same exemplary case, the shunt **18** is operated with pulses of about 1 μsec, an arc may initiate and may continue for about 900 μsec. Thus there appears to be a lower limit for effective shunt pulse time and that lower limit is about 1 μsec.

There may also be an upper limit for effective shunt pulse time in the context of the present invention. The present invention allows for shunting with a solid-state switch employed at its pulse rating. As described in an earlier example, a switch with a pulse rating of 1500 may be much smaller and lighter than a switch with a continuous conduction rating of 1500 amps. In order to safely use the smaller and lighter switch, it must be allowed to conduct for only brief periods, i.e., pulses. If the pulses are too long or are too closely spaced in time, the smaller and lighter switch may no longer perform safely. It has been found that a cumulative elapsed time of all shunt pulses in a single current interruption should not exceed 50% of the surge period. Furthermore, it has been found that no single one of the shunt pulses should exceed 20% of the surge period. In the exemplary case under consideration these principles suggest that a shunt pulse should not exceed 20 μsec.

In one embodiment of the present invention, a method may be provided for interrupting current in a circuit under load conditions. Such a method **500** may be illustrated in flowchart format in FIG. **5**.

In a step **502**, voltage may be continuously detected at current-interruption contacts (e.g., the voltage V**1** may be detected at the contact **10** of the contactor **14**). In a step **504**, a voltage signal may be produced which is indicative of current at the contacts (e.g., a voltage drop V**2** across a resistor may be indicative of current in the conductor **18** as well as current at the contact **12** of the contactor **14**).

In step **506** the voltages of steps **502** and **504** may be periodically sampled (e.g., by the arcing-condition determination block **408**). In a step **508** a combination of the voltages of steps **502** and **504** may be analyzed to determine if sufficient power is present at the contacts to initiate arcing (e.g. the block **408** may perform an analysis of V**1** and V**2** and make a time-related comparison to determine if surge power is high enough to initiate arcing). In the event that arcing potential is determined to exist, a step **510** may be initiated in which shunting of current around the contacts may be performed for a predetermined time (e.g., the solid-state switch **24** may be closed responsively to a signal **414-1** from the driver **414**). In a step **512**, the shunt may be opened (e.g., the switch **24** may open in response to signal **414-1** from the driver **414**, which may act responsively to signals **412-1** or **416-1**).

After step **512** may be completed, the step **508** may be re-initiated to determine in arcing potential may exist. If arcing potential is determined to exist, step **510** and **512** may be re-initiated. When and if performance of step **508** may determine that arcing potential does not exist, step **510** may not be initiated.

It should be understood, of course, that the foregoing relates to exemplary embodiments of the invention and that modifications may be made without departing from the spirit and scope of the invention as set forth in the following claims.

We claim:

1. An electrical power circuit comprising:
a contactor with movable contacts;
an electrical shunt to by-pass current around the contacts; and
a pulse control to:
produce multiple activations of the shunt during movement of the contacts away from each other; and
produce multiple deactivations of the shunt during said movement of the contacts.

2. The contactor of claim **1** wherein the contactor is rated to interrupt current in the circuit when the circuit is supplying power to a load.

3. The contactor of claim **1** wherein the contactor is rated to interrupt short-circuit current in the circuit.

4. The contactor of claim **3** wherein the contactor is rated to interrupt direct current.

5. The contactor of claim **1** wherein the electrical shunt comprises a solid-state switch.

6. The contactor of claim **1** wherein:
the contacts move apart from one another during a first time period;
the shunt is operated in a series of pulsed operations during the first time period; and
none of the pulsed operations extends individually for more than 20% of the first time period.

7. The contactor of claim **6** wherein a cumulative elapsed time for all of the pulsed operation does not exceed 50% of the first time period.

8. The contactor of claim **6** wherein none of the pulsed operations is performed for more than 20 microseconds (μsec) or less than 1 μsec.

9. A method for interrupting current in a circuit under load conditions comprising the steps of:

moving conducting contacts away from one another for a predetermined time period;

detecting electrical power at the contacts during the step of moving the contacts;

determining if the detected power is sufficient to initiate arcing at the contacts;

performing multiple operations of an electrical shunt around the contacts during the predetermined time period;

disabling the electrical shunt multiple times during the time period: and

passing power between the contacts during said moving whenever the electrical shunt is disabled.

10. The method of claim **9** wherein:

the step of moving the contacts is performed for a first period of time; and

the step of operating the electrical shunt is performed in at least one pulse having a pulse time period no greater than 20% of the first period of time.

11. The method of claim **9** wherein:

operating the electrical shunt is performed in a series of pulsed operation steps; and

disabling the electrical shunt is performed in a series of pulsed operations intervening the steps of operating the shunt.

12. The method of claim **11** wherein:

the step of moving the contacts is performed for a surge period of time; and

pulsed operations of the shunt are performed in pulses of no more than 20% of the surge period.

13. The method of claim **9** wherein:

the step of operating the shunt comprises closing a solid-state switch; and

the step of operating the shunt is completed within a time that does not exceed a time period on which a pulse-rating of the switch is based.

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